How UV-C energy works in HVAC applications: Part 1

This first of this three-part series describes UV-C light and how it is applied as a clean-up tool in all types of air conditioning systems.

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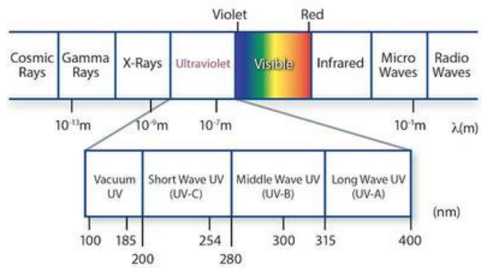
11/03/2013

Light energy in the ultraviolet-C (UV-C) wavelength has been used extensively in HVAC equipment since the mid-1990s to improve indoor air quality (IAQ) by eliminating the buildup of biofilms and other organic contaminants on the surfaces of system components, including cooling coils, plenum interiors, drain pans, and air filters. UV-C works by disassociating elemental bonds, which in turn disinfects and disintegrates organic materials.



In new systems, such buildups are avoided by the continuous cleaning of equipment with UV-C. In retrofit applications, UV-C eradicates organic matter that has accumulated and grown over time, and then prevents it from returning.

Although UV-C is a relatively simple technology, many engineers, building owners, and other facility professionals are mystified about how UV-C works and how to apply it cost effectively. Mystification leads to mistrust.

This three-part feature addresses the aspects of UV-C technology and the applications that seem the most awkward using ASHRAE guidelines found in Chapter 60: Ultraviolet Air and Surface Treatment in the 2011 ASHRAE Handbook – Applications. This first installment describes the nature of UV light, that is, electromagnetic radiation at a wavelength of 253.7 nanometers (nm) labeled "UV-C," and how properties of UV-C light have been applied as a clean-up tool within all types of air conditioning systems.

The second part will explore how UV-C light is generated by lamps that are very similar to fluorescent lamps found in commercial ceiling light fixtures. The topics of lamp life and replacement schedules also are covered to set the stage for using UV-C lamps in HVAC systems. The final installment in the series will discuss how UV-C lamps are applied within HVAC systems to clean cooling coil surfaces, drain pans, air filters, and ducts for the purposes of attaining and maintaining "as-built" cooling capacity, airflow conditions, and IAQ.

UV light comprises a segment of the electromagnetic spectrum between 400 and 100 nm, corresponding to photon energies from 3 to 124 eV. The UV segment has four sections, labeled UV-A (400 to 315 nm), UV-B (315 to 280 nm), very high energy and destructive UV-C (280 to 200 nm), and vacuum UV.

We all are familiar with the deleterious effects of UV transmitted by sunlight in the UV-A and UV-B wavelengths, giving rise to UV inhibitors, or blocking agents, which are found in glasses and lotions. We are also familiar with products engineered to withstand the effects of UV radiation, such as plastics, paints, and rubbers. However, unlike UV-A and B, the UV-C wavelength has more than twice the electron volt energy (eV) as UV-A, and it is well absorbed (not reflected) by organic substances, adding to its destructiveness. Learn more about the electromagnetic spectrum in a video from NASA.

UV-C's germicidal effects are well proven. It owes these effects to the biocidal features of ionizing radiation, that is, UV-C does far more damage to molecules in biological systems than can temperature alone. Sunburn, compared to the sensation of warmth, is one example of that damage. Sunburn is caused by sun striking living cells in the epidermis and killing them; the redness is the increased capillary action and blood flow enabling white blood cells to remove the dead cells.

Ionization drives UV-C's power to alter chemical bonds. It carries enough energy to excite doubly bonded molecules into a permanent chemical rearrangement, causing lasting damage to DNA, ultimately killing the cell. Even a very brief exposure can render microbial replication impossible. After being killed, organic remnants are subject to photo-degradation (disintegration), a key feature of UV-C energy.

UV-C is absorbed by the ozone layer and much of the atmosphere, and does not make it to Earth's surface; vacuum UV resides principally outside of the atmosphere.

Exposure and consequent dosage is the quantity of UV-C light absorbed over a specific period of time. A 2010 study commissioned by ASHRAE and the Air Conditioning, Heating, and Refrigeration Institute (AHRI) found that even the most sophisticated organic compounds suffer from exposure to small dosages of UV-C energy. Because UV-C lamp installations in HVAC applications operate 24/7, time is infinite, so surface materials are both disinfected and disintegrated. Once gone, they won't re-form as long as the lamps are maintained.

Unlike manufactured compounds, the mostly simple organic debris as found on coil surfaces are fairly easy to degrade. And because aluminum is among the best inorganic reflectors of the UV-C wavelength, UV-C energy is easily directed deep into and throughout a cooling coil.

The next installment in this three-part series will set the stage for using UV-C lamps to disinfect HVAC system components.

Forrest Fencl is president of UV Resources. He is the writer or co-writer of 15 patents, is an ASHRAE Fellow, and formerly an ASHRAE Distinguished Lecturer. He has authored numerous papers and articles and several ASHRAE Handbook chapters related to ultraviolet air and surface treatment.

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HUGH , CA, United States, **12/03/13 06:21 PM**:

This article, like many, addresses the surface disinfection issue. However, from a disease transfer point of view treating the flowing air is the more demanding task, especially for microbes smaller than MERV 13 -14 can capture. The power level must be considered and must be orders of magnitude higher than the surface treatment due to the limited exposure time. It would be valuable to gather comments and guidance from experience including addressing any Ozone that may be produced with these higher power UVC disinfecting systems.

How UV-C energy works in HVAC applications: Part 2

The second installment of this three-part series explores how lamps similar to fluorescent lamps generate UV-C light.

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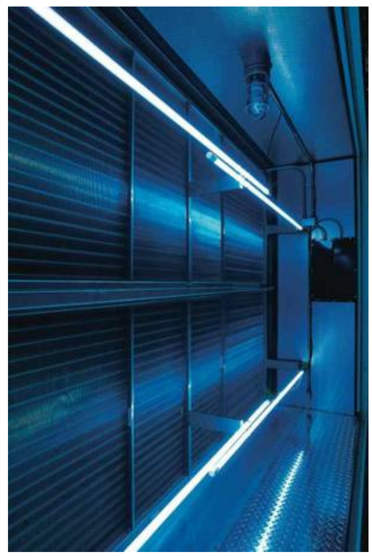
11/17/2013

Part 1 of this three-part series covered the nature of UV-C light and how UV-C is harnessed by lamps, which are used in HVAC systems. This installment discusses how lamps similar to fluorescent lamps generate UV-C.

UV-C lamps and lamp replacements

Modern UV-C lamps are very similar to fluorescent lamps typically found in ceiling fixtures. Both types of lamps are manufactured on fluorescent lamp machines in similar form factors (lengths and diameters), and they operate using identical electrochemical processes: an electric discharge through argon gas strikes mercury vapor to generate a photon with a wavelength of 253.7 nm (typically called UV-C), which is invisible.



UV-C lamps differ slightly from their fluorescent counterparts in that the UV-C lamp's glass envelope is a highly engineered, UV-C transparent glass. This allows the 253.7 nm wavelength to transmit through the lamp envelope unfiltered. Fluorescent lamps, however, use ordinary glass that is coated with phosphors on its interior surface. The UV-C energy is contained to excite the phosphors to glow (fluoresce) in the visible light range.

That being said, what gives UV-C lamps their characteristic blue hue, as shown in Figure 1?

A typical UV-C lamp produces about 90% of its energy in the UV-C wavelength. About 4% of its energy is given up as heat, and the rest (~5%) is in the visible light range that is medium blue in color. This blue color results from the argon gas in the enveolpe.

The similarities between UV-C lamps and fluorescent lamps providemany benefits. They can be constructed on the same type of machine and in the same form factors, reducing manufacturing, packing, and shipping costs to offset much higher material costs. They can also be stored and recycled in the same manner. UV-C lamps are typically warranted to provide more than 80% of their initial output over a 9,000-hour period. Because UV-C lamps should be operated continuously, the corresponding 8,760 hours of a 24/7 schedule also fits conveniently into annual re-lamping schedules.

Attempting to run UV-C lamps longer than 9,000 hours produces individual lamp outages, so maintenance staff must monitor them routinely to know what to replace. Replacing lamps as they burn out requires a larger inventory of replacement lamps for when the lamps begin to fail in larger numbers.

Like fluorescent lamps, UV-C lamps come in a variety of types and sizes, including single-ended and double-ended lamps. The single-ended lamps have all of the starting and ending terminals (pins) contained in the lamp base. They are used in several lamp systems, some of which allow the lamps to be inserted through a plenum or duct into the airstream, typically downstream of the cooling coil.

Double-ended lamps have pins at both ends, come in many varieties, and are installed into specific length fixtures usually containing the ballast like a fluorescent fixture. Typically, all lamp types are available in high output (HO) and standard output (SO) varieties. The difference between them is their Watt rating and ballast size. HO lamps are usually recommended because they are less expensive on a per-lamp-Watt basis.

Another consideration is opting for encapsulated lamps, which have a transparent polytetrafluoroethylene (PTFE) coating over the glass envelope. Encapsulated lamps hermetically seal UV-C lamps in case of breakage. Should an accident occur, broken glass and mercury will remain within the lamp encapsulate.

In the last installment of this three-part feature, learn how UV-C lamps are applied within HVAC systems to clean cooling coil surfaces, drain pans, air filters, and ducts to attain and maintain "as-built" airflow conditions and indoor air quality.

Forrest Fencl is president of UV Resources. He is the writer or co-writer of 15 patents, is an ASHRAE Fellow, and formerly an ASHRAE Distinguished Lecturer. He has authored numerous papers and articles and several ASHRAE Handbook chapters related to ultraviolet air and surface treatment.

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How UV-C energy works in HVAC applications: Part 3

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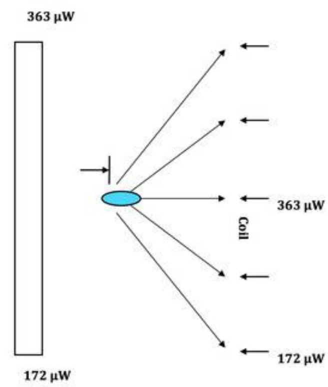
Forrest Fencl, UV Resources, Santa Clarita, Calif.
12/01/2013

The first two parts of this series covered the nature of UV-C light and how lamps similar to fluorescent lamps harness UV-C light.

This final installment explores how UV-C lamps are applied in HVAC systems to clean cooling coil surfaces, drain pans, air filters, and ducts to attain and maintain "as-built" capacity and indoor air quality.



Three tiers of benefits

UV-C systems provide three levels of benefits when applied to HVAC systems.

Level 1—HVAC system efficiency: UV-C eliminates and/or prevents the buildup of organic material on the surfaces of cooling coils, drain pans, and interior duct surfaces. This improves airflow, returns and maintains the heat-transfer levels of cooling coils to "as-built" capacity, and reduces maintenance.

Level 2—IAQ: UV-C improves airflow levels and eliminates organic material on surfaces, which helps improve indoor air quality (IAQ) by reducing pathogens and odors. This improves occupant productivity, boosts comfort levels, and reduces sick time.

Level 3—economic impact: The impact that UV-C has on mechanical systems and occupants translates into substantial economic benefits, including reductions in energy consumption, energy cost, and carbon footprint; reductions in hot/cold complaints and maintenance actions associated with complaints; reductions in system downtime and staff time needed for chemical or mechanical cleaning; and increases in occupant satisfaction and productivity. On average, UV-C slashes 10% to 25% of HVAC energy use.

UV-C lifecycle

To receive these benefits, engineers need to apply simple methods of sizing, selection, and specifying a UV-C system during installation design. Contractors must correctly install the UV-C system, and facility staff must change the lamps annually and possibly perform other routine service. These activities can be grouped into the lifecycle phases of system design, installation, activation/commissioning, and operations and maintenance.

This article covers the lifecycle phase of system design, which includes sizing/selection of lamps, specifying the installation configuration and equipment, and selecting and specifying the controls.

Sizing, selection, and specification

For a complete design solution, engineers need to determine:

1. How much UV-C energy is needed to "do the job"
2. The lamp/ballast characteristics required to meet the individual application's operating conditions
3. The required quantity and configuration of lamps needed.

In its 2011 ASHRAE Handbook, *Applications*, Chapter 60.8, ASHRAE Technical Committee, TC2.9, established minimum irradiation levels of 50-100 $\mu W/cm^2$ (microwatts per square centimeter) for cooling coil applications. This requirement must be met as a "minimum" across the entire coil surface, including plenum ends and corners.

These engineering units, however, are unfamiliar to most practitioners. In lighting applications, sizing will generally resolve to lamp Watts. One accurate way to convert microwatts to lamp Watts is to use a form-factor translation consisting of a 1 sq meter surface with a 1-meter-long lamp located midway up the surface on a horizontal plane. The average lamp Watts and output of lamp manufacturers' published data shows that a 1 meter, high-output (HO) lamp is rated at 80 lamp Watts with an output of 245 $\mu W/cm^2$, at 1 meter distance (i.e., lamp surface to coil surface). UV-C lamps are usually installed at 12 in. from the coil surface, so the irradiance needs to be interpolated for that distance. Using the industry-accepted "cylindrical view factor model," the resulting irradiance is 1375 $\mu W/cm^2$.

While this number seems to be more than enough to meet the 100 $\mu W/cm^2$ recommended by ASHRAE, all operating conditions must first be taken into account. Some conditions effectively lessen or "de-rate" the performance of the lamps, such as air temperature and velocity. In fact, changes in these variables can positively affect design performance. In typical conditions of 500 fpm velocity and 55 F air temperature, lamps are de-rated by about 50%. Hence, the 1375 μW/cm^2 generated from a conventional high-output 80 lamp Watt bulb would now yield a dose irradiance of closer to 688 μW/cm^2—at 12 in. from the coil surface (Figure 1).

The next consideration factor is distance of the UV-C lamp to the plenum corners. The Kowalski view factor on the 1-meter example (Figure 1) shows this to be 25% of the highest mean value. Following through our earlier example, 688 μW/cm^2 is multiplied by 0.25, which results in 172 μW/cm^2 at the farthest points, or corners of the plenum.

The good news? UV-C dosage is increased based on reflectivity from the plenum's surface, or the amount of UV-C energy bouncing off of the top, bottom, and sides of a plenum toward the coil and elsewhere. Reflectivity sends UV energy everywhere to assure "all" surfaces are clean and disinfected. Different materials have different reflectance multipliers, as shown in Table 1. Using a galvanized steel plenum as an example, the multiplier is 1.50 (a 50% increase in UV-C energy); hence 172 μW/cm^2 x 1.50 = 258 μW/cm^2.

Even without considering reflectivity, the ASHRAE minimum UV-C dosage levels would be achieved at the farthest distance from the lamp to the coil. So, should less light be used? Because more light positively affects airborne microbial kill levels and because there is no significant cost savings for trying to use fewer or less-intense UV-C lamps, the 80-Watt HO lamps are highly recommended.

Metal	UV-C multiplier
Stainless steel	1.40
Galvanized steel	1.50
Aluminum	1.75

By working through the 1-meter example, the results can be used for future UV-C lamp installations as follows. The lamp was a 1-meter-long, 80-Watt HO lamp, irradiating a 1-sq-meter surface, or 10.76 sq ft. If the lamp wattage is divided by the square footage of the surface, it becomes (80/10.76) = 7.43 Watts/sq ft of coil surface area. This simpler method exceeds ASHRAE's recommendations of 100 μW/cm^2 at the farthest point, under typical operating conditions, when the lamp is located 12 in. from the coil surface!

After determining how much light is needed, engineers need to select the types of lamps that will provide the necessary light energy. Among the considerations are single-ended (Figure 2) and double-ended lamps (Figure 3). Double-ended lamps are used in specific length configurations and may confine the design in certain air handling units (AHUs). Single-ended lamps provide a lot of flexibility relative to a given plenum's width because they can be overlapped (Figure 4). Single-ended lamp fixtures can also be used in hard-to-access plenums and smaller rooftop units, as they are installed and serviced from outside the plenum (Figure 5).

Another consideration is whether to use PTFE encapsulation for safety. Encapsulated lamps trap the glass and mercury within a protective envelope should the lamp be broken. In most all applications there is a risk of lamp breakage. Encapsulation is recommended because the cleanup procedures for broken lamps can be extensive. Otherwise, guidelines for handling broken lamps can also be found in the 2011 ASHRAE Handbook – Applications, Chapter 60.

When using single-ended lamps, lamps of a single length can often be selected for the entire facility. This minimizes the number of spare lamps that must be kept on site, and it increases the purchasing power for buying in bulk when re-lamping on an annual schedule. As mentioned, this approach simply overlaps lamps and eliminates having to have combinations of sizes to get a perfect fit from one end of the coil bank to the other.

Installation design

For a complete UV-C installation design, engineers may want to specify certain other aspects of their design. This could include the calculated distance of 12 in. from the coil, and a lamp holder that will assure that the lamps are properly held and can be easily replaced. The installation design should also specify the required electrical power. Ballasts today are typically offered in 120-277 Vac designs for flexibility.

Controls

UV-C systems have relatively simple controls, most of which pertain to safety. A typical control package includes a cutoff switch located just outside the UV light installation's plenum door. Also included in that control circuit are the door interlock switches that turn off the lights when an access door is opened. Access doors can also be equipped with a view port to facilitate lamp inspections.

Another traditional control option is the radiometer, which can display lamp operating hours and a relative indication of UV-C output. However, radiometers can only monitor one lamp, and if that lamp stays on while others have failed, the measure may be meaningless. Also, lamps are much more reliable today and only lose as little as 15% of their initial output during 9,000 hours of operation, so the radiometer has lost favor.

Simple, self-powered current sensors that show whether a particular lamp/ballast combination is on or out are in greater demand today. Multiple lamp/ballast sensors can be fed into a replicator that allows one signal to the building management system (BMS) to represent up to eight lamp/ballast combinations (Figure 6). They also can be chained together to represent an infinite number of lamp/ballast combinations with one signal. Additional programming can be added to alert operators if a lamp or ballast is out, which eliminates the need to visit each AHU to check for failures, especially as the 9,000-hour useful life expectancy window approaches.

When controls are designed into the UV-C system, commissioning providers need to check that they are documented appropriately and functioning properly.

UV-C light is an incredibly effective and affordable technology for keeping critical components of commercial HVAC systems clean and operating to “as-built” specifications. Benefits of applying UV-C lamps in HVAC systems include greater energy efficiency, lower operating expenses, fewer occupant complaints, and better IAQ.

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